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An Innovative Workstation

James Villarreal
Artificial Intelligence Section / FM7
NASA Lyndon B. Johnson Space Center
Houston, TX

A SBIR (Small Business Innovative Research) contract was awarded to Analytics to develop a system which uses the faint magnetic fields generated by the mental processes of the brain as another route for computer control. The emphasis of this project is not on the direct control of a computer workstation by reading the operator's EEG signals, but to control the workstation, or better, to anticipate the user's needs with the combination of eye data, EEG data and task or workload data.

Analytics, through a previous SBIR, developed a workstation which used the operator's eye movements and position to determine the placement of the cursor on a computer screen. This paper will first provide a brain wave sensing technology overview and an introduction into the known rhythms or signals generated by the brain. This will be followed with a descriptive explanation of OASIS (Ocular Attention Sensing Interface System) and its intended integration into the proposed testbed.

Introduction

With the ever growing computer processing speed comes the growing informational exchange between man and machine. One interface design aspect deals primarily with the presentation or selection of information to the user. Another interface design aspect concentrates on control mechanisms such as the mouse to manipulate the data available to the user. This project's basic foundation is that both aspects should be addressed simultaneously.

Most advanced man machine interfaces are directed toward the cockpit. Complex machines have been developed to simulate the actual sensations and perceptions experienced by a pilot during flight. Should advanced interfaces be confined to just the super cockpit? Could such interfaces benefit the scientist or engineer in recreating known concepts? Clearly, many scientific problems, especially those that can be represented in three dimensions, would benefit by a greater interaction with the computer.

Electrical/Magnetic Sensing Techniques Overview

Electroencephalography (EEG) is probably the most familiar recording technique. EEG's are routinely used by the the medical community in diagnosing certain sleep or mental disorders. Also, the EEG along with heart rate and perspiration detection instruments are used by interrogative polygraphy or colloquially known as "lie detection". Alpha rhythms were first discovered by Berger (1929). It is interesting to note that alpha rhythms were discovered with galvanometers (a magnetic sensing device). It did not become feasible to record alpha rhythms until the introduction of the vacuum tube amplifier in the 1940's. A major problem with the early vacuum tubes were their inherent noise. Today's solid state low-noise amplifiers are capable of amplifying signals from DC up into the kilohertz regions with little degradation in the signal. In fact, the signals amplified by these devices are so clean that the principle noise source now comes from the neighboring mental activity of the area under investigation. The signals being detected by the EEG scalp probes are not only from the activity directly under the probe but also from other distant sources. EEG readings then are the average effect of several activity sources.

The signals seen by the EEG are frequencies which range from between 1 cycle per second to 13 cycles per second. Different frequency bands represent different states a person is undergoing. An EEG can easily determine whether a person is at rest, daydreaming, sleeping, or mentally active.

Probably the most familiar type of EEG signal is the alpha rhythm. Its range is generally between 8 to 12 cycles per second. An alpha rhythm is characteristic of a person in a relaxed state with the eyes closed but not necessarily sleeping. Its signal is greatest in amplitude over the posterior portions of the head, and it occurs in spindles with varying durations. The spindles can be inhibited by having a person open his eyes. This should indicate that the alpha rhythm is directly correlated with visual activity. However, after a person has had his eyes open and slips into a boring situation, it is possible to have the alpha rhythms reappear even with the subject's eyes open.

Another interesting EEG reading is the beta rhythm. It is characteristic of signals of 13 cycles per second and above. Beta activity is present when an individual has her eyes open and is mentally active. The signal is present in the anterior quadrants of the head.

Theta rhythms are characteristic of signals in the frequency band between 4 and 7 cycles per second. These rhythms are found in both adults and children under emotional stress. The delta rhythms are present during sleep and are in the 1 to 3 cycle per second frequency range. Delta rhythms appear during sleep and characterize the various sleep levels. Due to their dependence on the sleep state, they are not useful for this project.

Other signals which can be detected by EEG's are those that are evoked by certain stimuli. Evoked potentials, then, are time-locked to specific events. Because of their direct relation to cognitive factors the N1, P2, and P3 are particularly interesting to this project. The identifying characteristic for the evoked potential is easily understood by noting that the preceding letter signifies whether the signal is negative (N) or positive (P). The number following the letter indicates how long after the stimulus is given that a response is expected. Therefore, for N1 the signal is negative and occurs 100 milliseconds after the stimulus.

First discovered by Sutton (1963) is the classic P300 (P3) phenomenon. The fact that a component of the auditory related potential occurred about 300 msec after an unexpected stimulus was quite exciting This led to more discoveries of other event related responses. Due to the low frequency characteristic of P3, it is useful only in slowly developing situations. P3 is evoked by surprising or unexpected occurrence of both visual and auditory stimuli. However, for odd visual stimuli, the response is usually more on the order of 400 msec. Its long reaction time can be understood when we imagine a confrontation with a surprising situation ... we absorb the stimulus ... we analyze the stimulus ... we detect an anomaly ... we react.

The N1 evoked potentials are activated by auditory stimuli. Magnetic studies by Pellizone (1984) showed that the source of N1 is in the auditory cortex. It has been demonstrated that the amplitude of these signals are strongly related to the subject's level of attention. Unfortunately, the characteristics of this signal vary across individuals.

Almost anything stated of N1 is also true for P2, except that far less is known of P2 than N1. Magnetic studies of this phenomenon have shown physically separated activity sources within the brain.

With every electrical field there is an associated magnetic field. Unlike EEG which requires that probes be placed on the scalp, magnetoencephalogram (MEG) sensors are placed reasonably close to the scalp but not required to touch. The principle advantage this offers is the elimination of unwanted "skin" noise which poses a large problem for EEG recordings. As was indicated earlier, both theoretical and experimental EEG studies have shown that different tissues and bone surrounding the brain attenuate or 'smear' the potentials that reach the scalp (Geisler and Gerstein, 1961; De Lucchi et al., 1962; Cooper et al., 1965). However, MEG studies have demonstrated that concentric layers in the head do not affect the magnetic fields produced by sources (dipoles). Therefore, MEG is not subject to 'smearing' and can thereby detect sources which occupy small regions (Grynszpan and Geselowitz, 1973).

Not until the introduction of a Superconducting Quantum Interference Device (SQUID) could magnetic fields emanating from the brain be detected. The brain's magnetic field has a strength on the order of magnitude of 10^{-8} Gauss (G) (Reite et al., 1976). In comparison, the earth's magnetic field has a strength in the order of 0.5 G (Geselowitz, 1979). Strong fields such as the earth's can be filtered with a gradiometer. For a SQUID to detect magnetic fields in the order of magnitude of 10^{-10} G, the sensors must operate in the superconducting region. Not until recent breakthroughs in superconducting materials operating at near room temperatures (Chen, 1987) was this possible without the use of liquid helium to achieve the superconducting effect. Supercooling demanded cryogenics which made any research with SQUID's costly prohibitive. At the writing of this paper only one commercial company, that the author is aware of, has been able to fabricate metals for commercial use. But, as with other electronic technologies, fabricating superconducting materials for commercial use is expected to soon become commonplace.

The Eye/Brain/Task Testbed

Computer interfaces, as presently known, are all basically passive. That is, a computer does not respond to the user without the user's request. Ideally, an intelligent system would know when intervention is appropriate. The passive role of "ready servant" requires that an operator's needs are anticipated. As an analogy to the ready servant, consider the skilled nurse assisting the surgeon anticipating the needs of the surgeon before the request is made. As the computer begins to take on a more active role, the need for the machine to know the operator's activity and intentions becomes essential. This phenomenon we experience everyday, but, may never fully realized. In carrying conversations with other individuals we unconsciously notice the person's facial expressions, posture, eye contact, and variations in speech to anticipate what the person's intentions are and what he will be saying. Being able to detect these subtleties using optics and computers would be extremely difficult. But, it is believed that using instruments such as MEG or EEG which can estimate a person's mental state, practical steps are being taken toward knowing a person's intention with a computer. The Eye/Brain/Task (EBT) project will be a testbed to test these theories.

Before an explanation for how the various electro/megneto recording techniques will be used on this project, a description of the Ocular Attention Sensing Interface System (OASIS) should be provided. OASIS is comprised of a testbed and prototype eye/voice control system. Basically, a low intensity infrared light is shined onto a person's eyes. The pupils of the eye reflect the light to an oculometer which determines eye position. This information is then fedback to the monitor in the form of a cursor. Therefore, this prototype allows an operator to move a cursor on the screen by simply moving the eyes. A voice recognizer also allows the operator to give verbal commands. By integrating eye data with brain wave activity, it then becomes possible to determine where a person is looking in relation to the screen and the person's associated level of attention within the region.

To fully complete the required components to determine a person's intention, an indicator of the workload or task is still required. The full integration of the three components, eye, brain, and task can best be explained with an example. Imagine a scene as depicted in figure 1. The object of this task is to direct as many vehicles as possible through the obstacles to reach the other side. "Looking" at a vehicle and giving it the verbal command "GO" propels it forward toward the obstacles. Another vehicle can then be selected and also given the command to proceed. By this time it probably becomes necessary to service the first vehicle and direct it to make either a "LEFT" or "RIGHT" turn. Another vehicle is then selected and also given the command to proceed forward. What has been developed here is a rich environment which allows a researcher to correlate task information with brain activity and visual information. Audio stimuli can also be interjected.

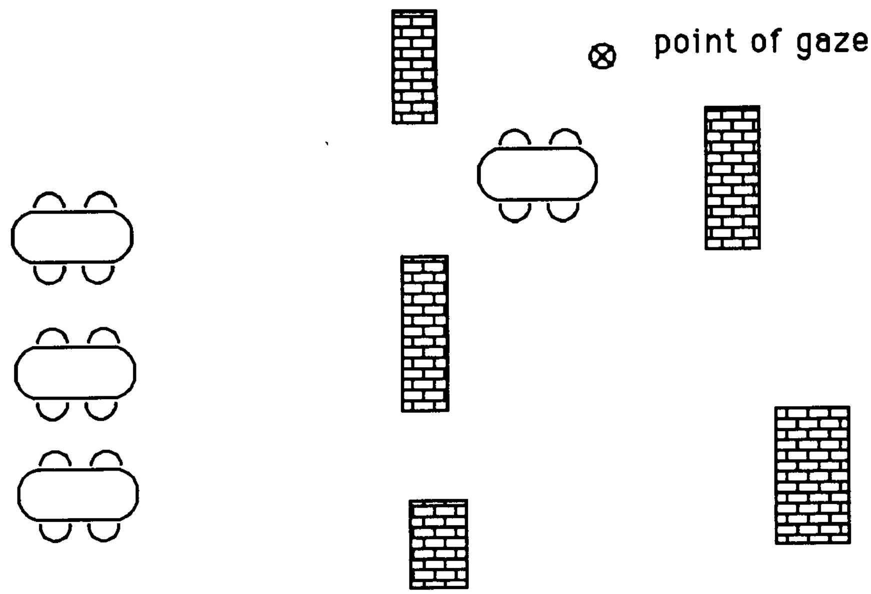

Figure 1. Vehicle manuevering task

Conclusion

The Phase II effort will concern itself with the development of a prototype EBT testbed, and, through applied research and development, the refinement and optimization of the system. The principle objective of the proposed Phase II effort is to develop a laboratory testbed that will provide a unique capability to elicit, control, record, and analyze the relationship of operator task loading, operator eye movement, and operator brain wave data in a computer system environment. Additionally, the testbed will have the capability to serve as the vehicle for demonstrating computer control using brain waves at a future time.

Acronyms

DC	direct current
EBT	Eye/Brain/Task
EEG	electroencephalography
G	Gauss
MEG	magnetoencephalography
OASIS	Ocular Attention Sensing Interface System
SBIR	Small Business Innovative Research
SQUID	Superconducting Quantum Interference Device